The "Deep Mystery" of Melted Steel

There is no indication that any of the fires in the World Trade Center buildings were hot enough to melt the steel framework. Jonathan Barnett, professor of fire protection engineering, has repeatedly reminded the public that steel--which has a melting point of 2,800 degrees Fahrenheit--may weaken and bend, but does not melt during an ordinary office fire. Yet metallurgical studies on WTC steel brought back to WPI reveal that a novel phenomenon--called a eutectic reaction--occurred at the surface, causing intergranular melting capable of turning a solid steel girder into Swiss cheese.

Materials science professors **Ronald R. Biederman** and **Richard D. Sisson Jr.** confirmed the presence of eutectic formations by examining steel samples under optical and scanning electron microscopes. A preliminary report was published in *JOM*, the journal of the Minerals, Metals & Materials Society. A more detailed analysis comprises Appendix C of the FEMA report. *The New York Times* called these findings "perhaps the deepest mystery uncovered in the investigation." The significance of the work on a sample from Building 7 and a structural column from one of the twin towers becomes apparent only when one sees these heavy chunks of damaged metal.

A one-inch column has been reduced to half-inch thickness. Its edges--which are curled like a paper scroll--have been thinned to almost razor sharpness. Gaping holes--some larger than a silver dollar--let light shine through a formerly solid steel flange. This Swiss cheese appearance shocked all of the fire-wise professors, who expected to see distortion and bending--but not holes.

A eutectic compound is a mixture of two or more substances that melts at the lowest temperature of any mixture of its components. Blacksmiths took advantage of this property by welding over fires of sulfur-rich charcoal, which lowers the melting point of iron. In the World Trade Center fire, the presence of oxygen, sulfur and heat caused iron oxide and iron sulfide to form at the surface of structural steel members. This liquid slag corroded through intergranular channels into the body of the metal, causing severe erosion and a loss of structural integrity.

"The important questions," says Biederman, "are how much sulfur do you need, and where did it come from? The answer could be as simple--and this is scary- as acid rain."

Have environmental pollutants increased the potential for eutectic reactions? "We may have just the inherent conditions in the atmosphere so that a lot of water on a burning building will form sulfuric acid, hydrogen sulfide or hydroxides, and start the eutectic process as the steel heats up," Biederman says. He notes that the sulfur could also have come from contents of the burning buildings, such as rubber or plastics. Another possible culprit is ocean salts, such as sodium sulfate, which is known to catalyze sulfidation reactions on turbine blades of jet engines. "All of these things have to be explored," he says.

From a building-safety point of view, the critical question is: Did the eutectic mixture form before the buildings collapsed, or later, as the remains smoldered on the ground. "We have no idea," admits Sisson. "To answer that, we would need to recreate those fires in the FPE labs, and burn fresh steel of known composition for the right time period, with the right environment." He hopes to have the opportunity to collaborate on thermodynamically controlled studies, and to observe the effects of adding sulfur, copper and other elements. The most important lesson, Sisson and Biederman stress, is that fail-safe sprinkler systems are essential to prevent steel from reaching even 1,000 degrees Fahrenheit, because phase changes at the 1,300-degree mark compromise a structure's load-bearing capacity.

The FEMA report calls for further metallurgic investigations, and Barnett, Biederman and Sisson hope that WPI will obtain NIST funding and access to more samples. They are continuing their microscopic studies on the samples prepared by graduate student Jeremy Bernier and Marco Fontecchio, the 2001–02 Helen E. Stoddard Materials Science and Engineering Fellow. (Next year's Stoddard Fellow, Erin Sullivan, will take up this work as part of her graduate studies.) Publication of their results may clear up some mysteries that have confounded the scientific community.

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